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DEVELOPMENT OF A FUZZY MULTI-OBJECTIVE MATHEMATICAL MODEL FOR HAZARDOUS WASTE LOCATION-ROUTING PROBLEM

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DEVELOPMENT OF A FUZZY MULTI-OBJECTIVE MATHEMATICAL MODEL FOR HAZARDOUS WASTE LOCATION-ROUTING PROBLEM

By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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Industries and manufacturers produce hazardous waste that causes long-term harm to human health, animal life, and the environment. Hazardous waste management (HWM) involves the collection, transportation, recycling, treatment, and disposal of hazardous waste under safe, efficient, and cost effective manner.

Researchers have presented different framework to illustrate required facilities and connection between these facilities for hazardous waste management. In the most of previous studies some important facilities such as recycling centers and connection between different facilities were neglected. Aforementioned in HWM definition, risk and cost are the most important criteria. Using total cost and total risk as objectives for the mathematical model present a good trade-off between environmental and economic aspects. Until recently, there have been some studies that used both objectives together.

Uncertainty is one of the important issues to deal with the real world problems. The generated hazardous waste quantity is not predictable precisely. Therefore, amount of waste is uncertain parameter. However, no research has been found that use fuzzy theory to address uncertainty of hazardous waste quantity.

A multi-objective location-routing problem is a NP-Hard problem. It is difficult to find Pareto optimal solution for these problems. This indicates a need to apply a Meta-heuristic method to solve these problems. However, far too little attention has been paid to use Meta-heuristic method in this field.

In this research, a fuzzy multi-objective mixed integer programming location–routing model for the hazardous waste is developed. This study considers uncertainty in generated hazardous waste quantity by using fuzzy parametric programming. The proposed model has two objectives: to minimize total costs, including transportation, operation, and initial investment costs as well as the saved costs from selling recycled waste; to minimize total risk including transportation risk and site risk by considering population exposure along the route and around each facility respectively. The aim of the model is to help decision makers to locate optimum number of facilities and finding set of routes. The results of the applied model show, it is possible to decrease the cost

value by marginally increasing the total risk value. Hence, two objectives are conflicting to each other. Two objectives can give a good trade-off between environmental (calculating total risk) and economic (calculation total cost) factors. Using fuzzy parametric programing proved that the waste quantity uncertainty has effect on the objectives function values, the optimum number of facilities and location of facilities. To solve the model a (fast elitist Non-Dominated Sorting Genetic Algorithm (NSGA-II)) and also the (weighted sum method (WSM)) were used and their results were compared to each other. MATLAB software is utilized for coding NSGA-II and GAMS software is utilized for coding WSM. The solved model demonstrates that NSGA-II can provide good efficient solutions in one time run than WSM. The model was applied for three different case studies. Also, a benchmark example was used to verify NSGA_II. To validate the model, a real case study of Klang city at Malaysia was applied. The results of the solved model show around 41% improvement of cost objective value in compare to the current method. However, there is not any method to measure hazardous waste transportation risk in current situation at Malaysia. Hence, value of the total risk objective can help to choose optimal set of routes and facilities under safe manner.

Abstrak tesis dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN MODEL MATEMATIK MULTI-OBJEKTIF SAMAR SISA BERBAHAYA UNTUK MASALAH LOKASI-ROUTING

Oleh

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Industri dan pengeluar menghasilkan sisa berbahaya yang menyebabkan kemudaratan jangka panjang kepada kesihatan manusia, haiwan dan alam sekitar. Pengurusan sisa berbahaya melibatkan aktiviti pengumpulan, pelabelan, pengangkutan , kitar semula, rawatan dan pelupusan sisa berbahaya. Pengurusan sisa berbahaya adalah satu isu kritikal disebabkan oleh risiko bagi mencari kemudahan yang berkaitan , dan juga laluan sisa antara kemudahan yang tidak diingini itu. Para penyelidik telah dibentangkan rangka kerja yang berbeza untuk kemudahan diperlukan dan sambungan antara kemudahan ini untuk pengurusan sisa berbahaya. Lebih daripada kajian sebelum ini diabaikan untuk menggunakan pusat kitar semula dalam rangka kerja mereka. Paling kajian hanya digunakan pusat-pusat rawatan dan pelupusan. Selain itu, hubungan antara beberapa pusat (seperti pusat-pusat rawatan dan pusat-pusat kitar semula atau generasi pusat dan pusat-pusat pelupusan) tidak diambil kira.

Disebutkan di atas dalam definisi HWM, risiko dan kos adalah kriteria yang paling penting. Menggunakan jumlah kos dan jumlah risiko sebagai objektif bagi model matematik boleh membantu pembuat keputusan untuk mempunyai keseimbangan yang baik antara aspek alam sekitar dan ekonomi. Sehingga baru-baru ini, terdapat beberapa kajian yang menggunakan kedua-dua objektif bersama-sama. Dalam objektif kos, Majoriti kajian sebelum ini tidak mengambil kira kos operasi bagi pusat-pusat yang berbeza, dan penjimatan kos daripada menjual bahan buangan dikitar semula. Juga, dalam pengiraan objektif risiko keseluruhan, risiko kemudahan mencari (risiko lokasi) sering diabaikan.

Di samping itu, terdapat pelbagai jenis bahan buangan berbahaya dan teknologi yang berbeza untuk merawat mereka. Pelbagai jenis bahan buangan dan keserasian teknologi tidak menganggap dalam jumlah yang besar penyelidikan sebelumnya. Di samping itu, model berkapasiti boleh membantu pembuat keputusan untuk mengambil kira keadaan sebenar untuk kemudahan dan laluan. Oleh itu, dengan menggunakan model berkapasiti boleh membantu untuk merumuskan masalah perkataan yang benar.
Ketidakpastian adalah salah satu isu penting untuk menangani masalah-masalah dunia sebenar. Jumlah sisa berbahaya yang dihasilkan adalah tidak menentu. Setakat ini,

bagaimanapun, tiada kajian telah mendapati bahawa menggunakan teori kabur untuk kekaburan kuantiti sisa berbahaya.
Satu objektif masalah lokasi laluan berganda adalah masalah NP-Hard. Adalah sukar untuk mencari penyelesaian optimum Pareto untuk masalah ini. Ini menunjukkan keperluan untuk memohon kaedah Meta-heuristik untuk menyelesaikan masalah-masalah ini. Walau bagaimanapun, perhatian terlalu sedikit telah dibayar untuk menggunakan kaedah Meta-heuristik dalam bidang ini.

Dalam kajian ini, pelbagai objektif integer campuran pengaturcaraan model lokasi routing kabur untuk sisa berbahaya dibangunkan. Kajian ini mengambilkira ketidakpastian dalam menjana kuantiti sisa berbahaya dengan menggunakan pengaturcaraan berparameter samar. Model dicadangkan mempunyai dua matlamat: mengurangkan jumlah kos , termasuk pengangkutan , operasi, dan kos pelaburan awal serta kos disimpan daripada jualan sisa dikitar semula; mengurangkan risiko pengangkutan dengan mempertimbangkan pendedahan terhadap penduduk di sepanjang laluan. Tujuan model ini adalah untuk membantu pembuat keputusan (DMS) mencari penyelesaian awal dalam mencari kemudahan pengurusan sisa bagi bahan buangan berbahaya dan juga laluan sisa antara kemudahan dengan mempertimbangkan objektif diatas. Dapatan dari model yang digunakan menunjukkan dua objektif yang bercanggah. Dua matlamat ini boleh memberi ‘tradeoff’ yang baik di antara faktor alam sekitar (dengan mengira jumlah risiko) dan ekonomi (dengan kos pengiraan keseluruhan). Jumlah setiap objektif dan lokasi kemudahan juga bergantung kepada keutamaan setiap objektif. Kaedah NSGA -II adalah jenis algoritma meta- heuristik dan juga kaedah kiraan wajaran (WSM) adalah jenis kaedah klasik digunakan untuk menyelesaikan model. Perisian MATLAB digunakan untuk mengekod model dengan kaedah NSGA-II. Perisian GAMS digunakan untuk mengekod model dengan WSM dan model ini diselesaikan dengan penyelesai CPLEX. Model yang diselesaikan menunjukkan NSGA-II boleh menyediakan penyelesaian yang cekap dalam satu janaan berbanding WSM . Model ini digunakan di dalam tiga kajian kes yang berbeza. Di samping itu, empat contoh digunakan untuk mengesahkan model dan juga penyelesaian kaedah yang dicadangkan. Akhirnya, satu kajian kes sebenar bandar Klang di Malaysia telah digunakan untuk sah model yang dicadangkan. Keputusan model yang diselesaikan menunjukkan peningkatan sekitar 41% bagi objektif kos dengan menggunakan kaedah yang dicadangkan dalam berbanding dengan kaedah sebelumnya. Juga, tidak ada apa-apa kaedah untuk mengukur jumlah risiko untuk mengangkut sisa berbahaya dan mencari kemudahan yang tidak diingini. Oleh itu, pembuat risiko bantuan objektif keputusan untuk memilih tapak yang sesuai untuk mencari kemudahan yang tidak diingini dan laluan sisa berbahaya antara kemudahan ini berkuat kuasa minimum kepada alam sekitar dan juga kehidupan manusia.

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I certify that a Thesis Examination Committee has met on 2 October 2014 to conduct the final examination of Omid Boyer Hassani on his thesis entitled "Development Of A Fuzzy Multi-Objective Mathematical Model For Hazardous Waste Location-Routing Problem" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U. (A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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This is to confirm that:

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LIST OF ABBREVIATIONS

HazMats	Hazardous Materials
HWM	Hazardous Waste Management
OR	Operation Research
LRP	Location-Routing Problem
NP-Hard	Non-Deterministic Polynomial Time Hard
NSGA-II	Non Dominated Sorting Genetic Algorithm
WSM	Weighted Sum Method
MCDM	Multi Criteria Decision Making
MADM	Multi Attribute Decision Making
MODM	Multi Objective Decision Making
DMs	Decision Makers
QAP	Quadratic Assignment Problem
MILP	Mixed Integer Linear Programming
LP	Linear Programing
MOO	Multi Objective Optimization
MOEA	Multi Objective Evolutionary Algorithm
EO	Evolutionary optimization
LA	Location Allocation
GAMS	General Algebraic Modeling System
SAW	Simple Additive Weighting
ELECTER	Elimination and Choice Expressing Reality
TOPSIS	Technique for Order Preference by Similarity to Idea Solution
AHP	Analytic Hierarchy Process

CHAPTER 1

INTRODUCTION

1.1 Background of Research

Industries and manufacturers produce hazardous waste that causes long-term harm to human health, animal life, and the environment. Hazardous wastes, which are typically ignitable, reactive, corrosive, and toxic, are produced by large scale and small scale industries. Hazardous wastes are a sub group of hazardous materials that are called HazMats briefly. Source of HazMats are often from kind of facilities that have harmful effect for population and also environments. In addition, destination of HazMats shipments can be like their generation nodes with same impacts (Erkut, Tjandra and Verter, 2007). The locations of these facilities have direct effects on routing hazardous material. Therefore, facility location decision can be performed with routing decision simultaneously. In order integration of facility location and routing problems, first a back ground for facility location models and location-routing models are presented.

1.1.1 Location model, and Location-Routing Model

Facility location is one of the sciences with one hundred years old background. With considering this history, facility location models still are attractive for researchers. In general, facilities are categorized in two groups. First group is desirable facilities which try to locate as close as possible to inhabitants such as fire station, hospitals, and universities. The second group is undesirable facilities that try to stay away as far as possible from population centers such as landfills, nuclear reactor, and prisons (Farahani, SteadieSeifi and Asgari, 2010).
In field of facility location science, Operation Research methods (OR) are helpful tools for decision makers. In operation research, the location-routing problem or LRP generally include to find optimal number of facilities, capacity of each facility and location of facilities as well as determining optimal set of routes to transport materials to their destination (Erkut et al., 2007). There are plenty of examples for using models with different objectives to locate undesirable facilities or location-routing models. In summary, the objectives are used in this field are as follow:

(1) Minimizing cost: include of initial investment cost, transportation cost, operation cost, and etc. (Samanlioglu, 2013).
(2) Minimizing risk: two kinds of risk are considered in LRP. Transportation risk for carrying HazMats and site risk or facility risk for locating an undesirable facility (M. Caramia, Giordani and Iovanella, 2010; Zhao, 2010).
(3) Maximizing equity or minimizing inequity (Current and Ratick, 1995).
(4) Minimizing population opposition (Rakas, Teodorović and Kim, 2004).

1.1.2 Hazardous Waste Management Definition and Framework

In recent years amount of reuse different materials and products are growing up around the world. The management of return flows of these materials is called reverse logistic management. Hazardous waste management involves collecting, transporting, treating, recycling, and disposing residues in a safe, efficient, and cost-effective manner (Nema and Gupta, 1999). According to the reverse logistic definition, waste management and hazardous waste management framework are sub-group of reverse logistic framework (Starostka and Grabara, 2010). Many researches try to introduce different framework of reverse logistic management with considering various reuse materials (Fleischmann et al., 1997). A framework illustrates required facilities and connection between these facilities. A mathematical Location-Routing model can be presented based on a framework. The most important objectives in previous mathematical models are risk and cost objectives for hazardous waste management problems (Alumur and Kara, 2007; Samanlioglu, 2013). By using cost and risk objectives, environmental and economic aspects are considered simultaneously.

1.2 Problem Statement

Mathematical models are helpful method to manage hazardous wastes. According to the previous studies, the main factors to develop a mathematical location-routing model for hazardous waste are included of framework structure (required facilities and connection between facilities), type of facilities, number of facilities, location of facilities, connection between facilities, type of wastes, amount of waste, compatibility of technology with waste, and considering logical constraints such as capacity for model. Also, the optimization method to solve multi-objective problems is important issue to have reasonable and effective results. The literature can help to highlight scientific gaps, which include the problem statement of this thesis.

Form the prior studies, researchers have proposed a framework for hazardous waste management (Alumur and Kara, 2007; Samanlioglu, 2013; Xiao, Zhao, Kaku and Xu, 2012b). In their proposed framework, different types of undesirable facilities and connection between these facilities were illustrated. The most studies use simple framework for (hazardous waste management (HWM)) without considering connection between different centers. Also, some important centers like recycling centers are often neglected. According to the HWM definition, previous studies, and real world requirement, a comprehensive framework with required centers and suitable connection between different centers is needed.

To develop a mathematical model on the basis of HWM definition and the proposed framework, two objectives is included minimizing total cost and minimizing total risk. Using total cost and total risk as objectives for HWM can help decision makers to have a good trade-off between environmental and economic aspects. Until now, there have been some studies that used both objectives together. In the most previous studies, some important costs such as operation cost and cost saving from selling recycled wastes did not consider for calculating real cost value. Also, to formulating total risk, applying site risk beside transportation risk often is neglected. Some important limitations such as

compatibility of treatment technology with various types of waste and also capacitated facilities and capacitated route did not use in great number of previous researches.

Ambiguities are one of the significant problems to formulate a real world problem (Bellman and Zadeh, 1970). However, some researchers have used Monte Carlo simulation or fuzzy theory to address uncertainty in mathematical model for waste management (Ahluwalia and Nema, 2006; Rakas et al., 2004). In this field amount of hazardous wastes can be considered as uncertain parameter. Based on the literature there is lack of using fuzzy theory to tackle uncertainty of hazardous waste quantity.

A location-routing problem with one objective is NP-Hard (non-deterministic polynomial time hard). Hence, a multi-objective location-routing problem is a combination of two NP-Hard problems (Alumur and Kara, 2007; Nagy and Salhi, 2007). It is difficult to find Pareto optimal solution for these problems. Moreover, large-sized problem and complexity of location-routing model prove a necessity for a Meta-heuristic method. To solve this problem non-dominated sorting genetic algorithm (NSGA-II) that kind of an evolutionary algorithm will be proposed. This algorithm is helpful to find better solution near the Pareto curve because of using more than one solution at a time (neighborhood solution method).

1.3 Thesis Objective

The main aim of this study is to develop a fuzzy multi-objective location-routing mathematical model for hazardous waste management with two objectives: to minimize total cost; to minimize total risk based on a proposed framework. This model can help decision makers to locate optimum amount of new undesirable facilities (treatment, storage, recycling, and disposal centers) as well as finding set of routes to transport hazardous waste. This model minimizes total cost and total risk in hazardous waste management system. To satisfy the main objective, a number of sub objectives must be accomplished as follow:

(1) To develop a fuzzy multi-objective mathematical model for hazardous waste location-routing problem.
(2) To apply NSGA-II meta-heuristic method to optimize the model, and to take result as Pareto front solution. The method will be coded by MATLAB software.
(3) To verify the proposed model by using literature and benchmark examples. Also, to validate model with a real example data.

1.4 Scope of the Study

Due to the availability of resources, the scope of this research is focused on formulating a location-routing mathematical model that can be applied for hazardous waste management systems. In development of the methodology, the multi objective decision making (MODM) are used for a hazardous waste locating-routing model. Also, Meta heuristic method (NSGA_II) and classic techniques (weighted sum method) are implemented for solving the model. In addition, using MATLAB and GAMS (CPLEX solver) software for codding and solving model are necessary.

Consequently, the scope of study is applied for the hazardous waste management systems. The application of model can be for municipalities, departments of environment, and also waste management companies. Meanwhile the model is not limited to only to locate optimal number of the undesirable facilities and finding set of routes, it can cover other problems for semi desirable facilities such as airports, radio towers, and fire stations that need dispersion for reasons.

1.5 Contributions of Study

At present, there have been little researches to find undesirable facilities location and also routing hazardous waste in set of routes between undesirable facilities simultaneously. However, there is no study that presented a comprehensive mathematical model for hazardous waste management with considering storage centers, treatment centers, recycling centers, and disposal centers together in the framework as well as connection between these centers. Also, using Fuzzy theory to address uncertainty for amount of produced hazardous waste in generation nodes are neglected in previous studies. In addition, utilizing minimization of total risk and total cost as objectives for this model can help decision makers to have a good trade-off between environmental and economic aspects. For this reason, operational cost for different facilities and also cost saving parameter for recycled hazardous wastes are used to have a more comprehensive model. Also, applying site risk beside of transportation risk for risk objective can calculate amount of risk more precise.

In the literature, different approaches are suggested for solving multi-objective location-routing model for hazardous waste. In this field, classical method such as weighted sum method, the lexicographic weighted Tchebycheff method, and Ɛ-constraint Method were used to solve problems. The classical methods need the several times running to obtain Pareto set solutions. In this research, NSGA_II algorithm that is a meta-heuristic approach is used to tackle this problem. NSGA-II algorithm can solve the model with one time running the program, and it can obtain more Pareto solutions than the classical methods.

1.6 The Structure of the Thesis

he thesis is organized into five separate chapters based on requires of this study. The chapters are shown the components of the research framework. The components of this research except Chapter 1 are as follow:

Chapter 2 presents an exhaustive literature on undesirable facility location models, hazardous material routing models, and location-routing models for hazardous materials. More ever, the concept of hazardous waste management will be defined. Also, different frameworks including various centers for hazardous waste management system will be illustrated. The definitions of multi criteria decision making (MCDM) and multi objective decision making (MADM) are presented that can help to formulate the proposed framework. In addition, fuzzy theory to address uncertainty in

mathematical models is explained. Lastly, different approaches to solve multi-objective models including classical approach and Meta heuristic methods are reviewed.

Chapter 3 presents the methodology of the thesis to develop a new mathematical model and solves it. In this chapter, the proposed framework for hazardous waste management is illustrated. Then, necessary parameters and decision variables to formulate the model are introduced. The fuzzy parametric programming is introduced to substitute the fuzzy model to a crisp model for solving. Thereafter, the new fuzzy mathematical model based on frame work and introduced parameters are developed. In addition, NSGA-II approach to solve this model is explained.

In Chapter 4 verification of the developed model and NSGA-II algorithm are checked by different examples. First a literature example is used to check feasibility of model. Then a benchmark example is chosen to verify the NSGA-II algorithm. Example three is used to compare results of NSGA_II approach with weighted sum method. Then, example four is applied to check effect of using fuzzy method in solution of the model (value of objectives and location of facilities). Lastly, a real example is utilized to show validity and applicability of the model in real world.

Chapter 5 provides the conclusion and summary of the research outcomes and also it explained how the objectives of the study are fulfilled. In the end, based on the obtained results, significant observations are presented and some issues are suggested for future research.

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